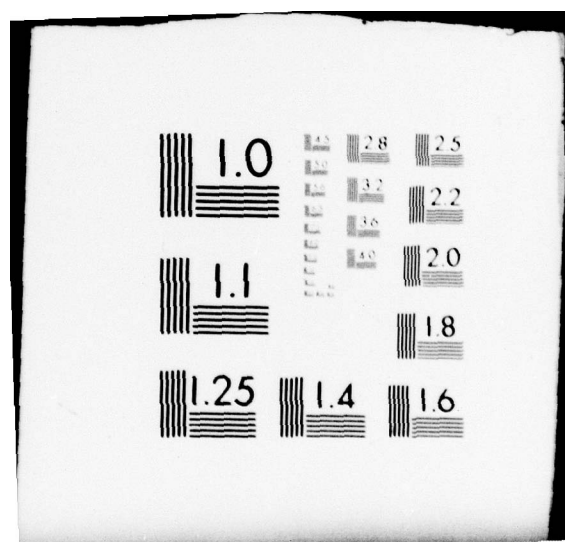| OF |

AD
A074772

END
DATE
FILMED
11-79
DDC

# LEVEL II

Project M-225    FINAL REPORT

## METHODS AND PROGRAMS
## TO UTILIZE SATELLITE INDIRECT SOUNDINGS
## IN
## ENVIRONMENTAL ANALYSIS AND PREDICTION

by

Manfred M. Holl
Meteorology International Incorporated
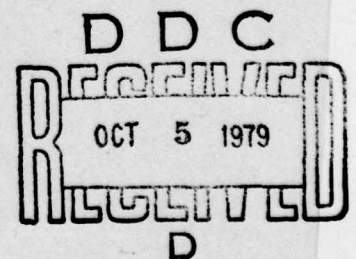September 1977

Performed for:

The Commanding Officer
Naval Environmental Prediction Research Facility
Monterey, California 93940

Performed under Contract No. N00228-76-C-3174

**D D C**

**RECEIVED**

OCT 5 1979

**D**

METEOROLOGY INTERNATIONAL INCORPORATED

Monterey, California 93940

054

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>METHODS AND PROGRAMS TO UTILIZE SATELLITE INDIRECT SOUNDINGS IN ENVIRONMENTAL ANALYSIS AND PREDICTION | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final report |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>MII-M-225 |
| 7. AUTHOR(s)<br>Manfred M. Holl | | 8. CONTRACT OR GRANT NUMBER(s)<br>N00228-76-C-3174 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Meteorology International Incorporated<br>205 Montecito Avenue<br>Monterey, California 93940 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>A370370G/076B/7F52-551-000-NEPRF W.U. 026:3-5 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Commander, Naval Air Systems Command<br>Department of the Navy<br>Washington, D. C. 20361 | | 12. REPORT DATE<br>September 1977 |
| | | 13. NUMBER OF PAGES<br>67 |
| 14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)<br><br>Naval Environmental Prediction Research Facility<br>Monterey, California 93940 | | 15. SECURITY CLASS. (of this report)<br><br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

| | |
|---|---|
| Satellite Sounders | Diagnosis of Clear-Column Radiances |
| Remote Sensing | Atmospheric Thermal-Structure Resolution |
| Blending by Weighted Spreading | Fields by Information Blending |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes CLRBLOK, a comprehensive programmed capability for the diagnosis of blocks of scanlines of multi-channel radiances measured by Special Sensor E of Defense Meteorological Satellite Program spacecraft. The measured radiances are diagnosed for their clear-column radiance components and for the associated estimates of reliability. The solution of the blending system of linear equations is accomplished by application of a novel method: Blending by Weighted Spreading with the algorithm shifting into an SOR mode
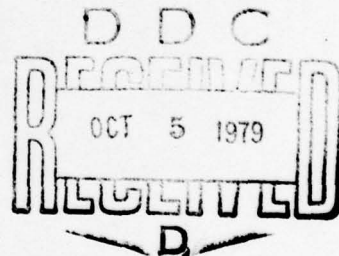
DD FORM 1473  EDITION OF 1 NOV 65 IS OBSOLETE

Block 20. Abstract (Continued)

Con$^t$

for those elements which have attained a prescribed criterion of absolute relevance. Also included is a method for assimilating the information in clear-column radiances, weighted as to reliability of the individual radiances and channel calibrations, for direct enhancement of the atmospheric thermal structure. This method includes the option to constrain the thermal structure to be statically stable. These information processing developments are applications of the Fields by Information Blending (FIB).

Accession For
NTIS GRA&I
DDC TAB
Unannounced
Justification

Per Hk. on file

Distribution/

Availability Codes

Dist    Avail and/or
        special

A

D D C
RECEIVED
OCT 5 1979

D

## TABLE OF CONTENTS

# METHODS AND PROGRAMS TO UTILIZE SATELLITE INDIRECT SOUNDINGS IN ENVIRONMENTAL ANALYSIS AND PREDICTION

## 1.    INTRODUCTION

### 1.1    The Assignment

The general objectives are methods and programs for utilizing remote soundings of the atmosphere from space for improving environmental analysis and prediction.  This technical report describes the development of a capability for diagnosing radiances measured by a multi-channel scanning radiometer, for inherent clear-column radiance estimates, and a method for using this diagnosed information for enhanced resolution of the atmospheric thermal-structure distribution.  Conceptions and formulations are described; complete details appear elsewhere, with the program documentation.

This project is a continuation of earlier work also performed by Meteorology International Incorporated.  The pertinent concepts and formulations for the diagnosis of measured radiances, for the inherent resolution of clear-column radiances, first appeared in a processing scheme which we denoted by the letters CLRX.  The scheme is based on an idealization of cloud structures and hence may be termed a diagnostic model. The CLRX model was designed for the diagnosis of individual scanlines measured by Special Sensor E (SSE) aboard Defense Meteorological Satellite Program (DMSP) spacecraft.  A later version of the model, named CLRXN, was developed for application to the Vertical Temperature Profile Radiometer (VTPR) sensor aboard NOAA spacecraft, again designed for diagnosing single scanlines but with exploitation of the greater proximity of adjoining scanlines.

The SSE is a radiometer designed to measure thermally-emitted infrared radiation from the earth-atmosphere system. Figure 1 is an example of the scan pattern of the SSE. The instrument scans from left to right in steps, providing 25 observation views (i.e., spots) along each scanline crosswise to the motion of the satellite. The surface field of view is about 20 nm in diameter directly below the satellite, becoming broadened and elongated at either end of the scanline. Eight radiation measurements are made at each scan spot. Six of the eight radiation observations are provided by SSE channels positioned at different wavelength intervals in the 15-$u\pi$ absorption band of carbon dioxide. The seventh SSE channel is located in the 12-$u\pi$ atmospheric window and the eighth channel senses radiation in a water-vapor absorption band near 18 $u\pi$.

The VTPR instrument is similar in complement of channels but differs in scanning geometry. The VTPR system and processing job stream have been described by McMillan et al. (1973).

Specific assignments of this project are

(i)   to improve and refine the diagnostic model to extend its applicability and to increase the information yield, and

(ii)  to organize the model into a programmed job stream which is capable of being run routinely on the computer system of the Fleet Numerical Weather Central (FNWC) for exploiting the SSE sensor of the DMSP satellite system.

These assignments have now been performed. When implemented into operations the system should have a major impact in advancing atmospheric analysis and prediction capabilities, provided that the channel source functions are properly calibrated and that the new diagnostic model, named CLRBLOK, is adequately tuned. This realization will provide a basis for further improvements in the design of satellite sounding systems, respecting sensors and scanning geometries, and for further operational advances in information assimilation and blending.
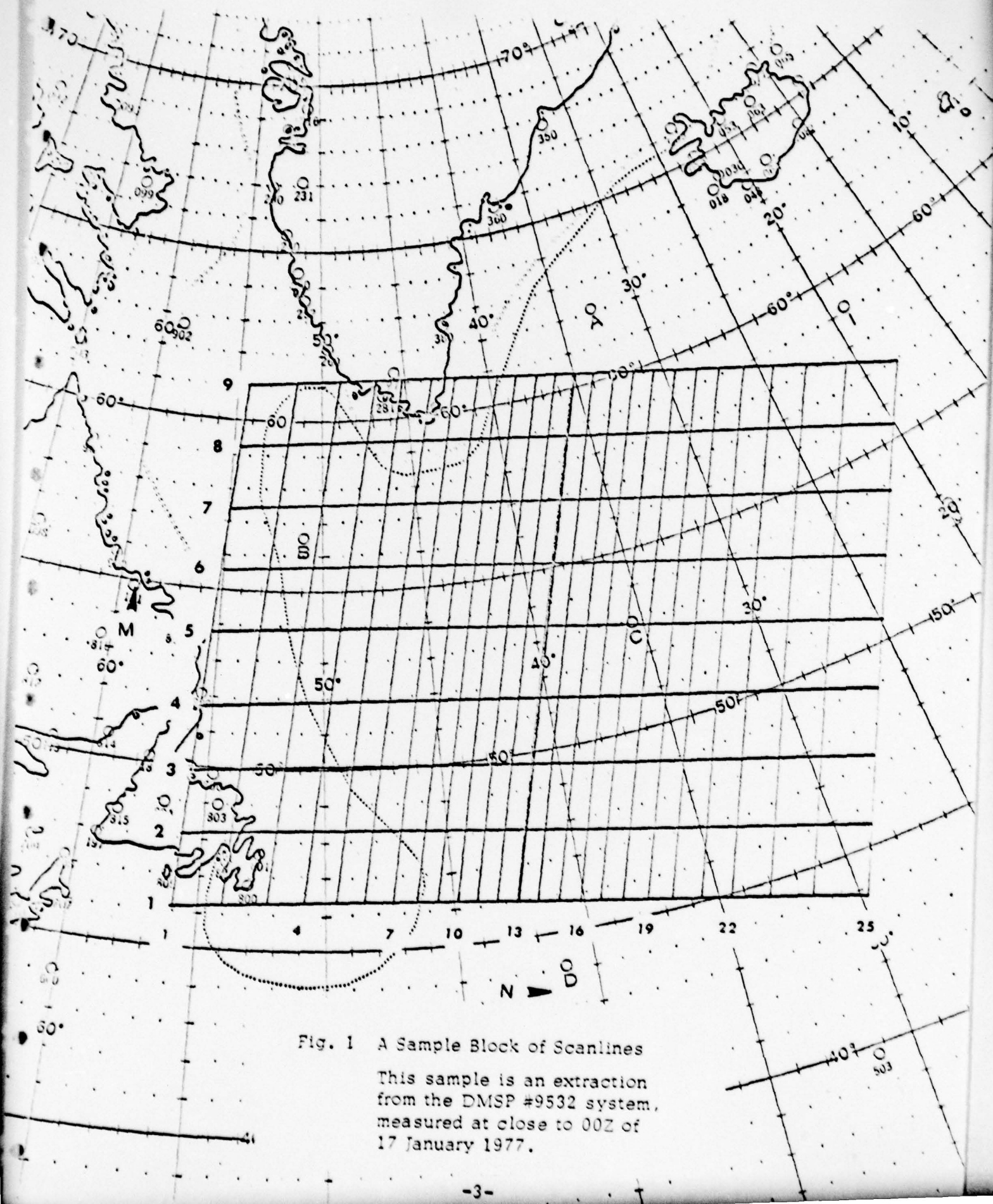
Fig. 1    A Sample Block of Scanlines

This sample is an extraction
from the DMSP #9532 system,
measured at close to 00Z of
17 January 1977.

## 1.2    Earlier Work

### 1.2.1    Specific Developments Performed for the Naval
Environmental Prediction Research Facility (NEPRF)

Meteorology International Incorporated (MII) performed Phases One
and Two of the development of techniques for operational exploitation of
satellite-observed sounding data for resolution of atmospheric thermal-
structure variabilities.  Developments under Phase One, reported by Holl
(1972, 1973a, 1973b), included a general scheme for blending clear-column
radiance estimates, weighted[1] as thermal-structure information, into
enhanced resolution of the thermal structure.  This scheme is an example
of what we call structure blending.  The subject version, named STRBLND,
also exploits the information that the atmospheric is statically stable in
the object scale of resolution.

The major development of Phase Two, reported by Holl (1975a), is
a basic scheme named CLRX for processing a scanline of multi-channel
views.  The scheme estimates which measured radiances are effectively
free of clouds, and diagnoses clear-column radiance components in regions
of cloud-contaminated views.  The diagnosed yield is limited to those
channels which, in penetrating down to cloud tops in a region, also include
some views which are at least partially clear to the depth of channel
penetration.  This basic version of CLRX contains the essential formulations,
with applicability limited to oceanic regions having little spatial variability
in sea-surface temperature.  There are additional limitations and a
complexity of contributing variances.

---

[1] In the FIB methodology developed by MII all parameter estimates
are generally weighted.  The weight of an estimate is equivalent to the
inverse of the associated variance.  The weight may refer to the reliability,
or independent worth, of a parameter estimate in a particular context, or to
the resolution accuracy of an estimate resulting from a blending of assembled
information.

The information inherent in measured radiance scans is highly variable. It is related to the characteristics of the cloudiness that is present. The diagnostic yield generally decreases from channel to deeper-seeing channel. The resolution weights range from minimal for channels fully blocked by cloud in a region, to very high in clear regions. Because of this great variability in information yield, the weight associated with a diagnosed clear-column radiance estimate is an essential component of the CLRX-diagnosed information. Because of this great variability in resolution, the diagnosed clear-column radiances cannot be categorically forced on the atmospheric thermal-structure analysis. Furthermore the resolution weights for the diagnosed clear-column radiances must be reduced for the associated channel-calibration variances if they are to be blended with other independent estimates and expressions of information bearing directly on the atmospheric thermal structure. The structure-blending scheme developed under Phase One encompasses these considerations.

Subsequent to Phase Two, MII tested the basic version of CLRX on a sample of scanlines measured by sensors of two DMSP satellites. Despite limitations of the available data sample (e.g., incomplete scanlines, a region of islands and sea-surface-temperature irregularities, and uncertainties in calibration relative to calculated first-guess radiance estimates) these tests demonstrated the functional capability of CLRX. The results were reported by Holl (1975b). The wide range in yield was quite apparent.

### 1.2.2 Diagnostic Model CLRXN

The development of an improved version of CLRX, designed for the scanning geometry of VTPR systems aboard NOAA spacecraft, was reported by Holl et al. (1976a). The VTPR scanlines are not as long in surface nadir-angle sweep, and are about three times more frequent along the orbit than are the

SSE scanlines. In applying the model, spots are paired for contrasting local radiance variabilities. In CLRXN these pairings are not limited to being of the same scanline. Three successive scanlines are analyzed for information elements used in the diagnosis of the clear-column radiance components of the middle scan. Several improvements were introduced in CLRXN.

Following delivery of the CLRXN software package to the National Environmental Satellite Service (NESS) of NOAA, that organization evaluated the capabilities.[2] The data base that was used for the test is a simulated package: VTPR radiances calculated for a variety of cloud structures. The CLRXN capabilities were considered to be superior to other procedures compared in the tests. Some advantages and some disadvantages of CLRXN were listed. Four advantages were stated to be distinct: CLRXN produces an independent estimate of the clear-column component of the window channel; a weighted clear-column estimate is produced for each channel and spot, and hence the potential information yield is greater; the value of the associated weights is recognized; the program can be run without independent sea-surface-temperature estimates and hence its extension to land areas is almost immediate for flat homogeneous terrain.

Three of the four listed disadvantages can readily be discounted or remedied: The apparent dependence on independent (i.e., first-guess calculated) radiance estimates is adjustable; clear-column estimates are not produced for spots at scanline extremes (i.e., spots 1, 2 and 22, 23) because the potential yield does not warrant the programming details; a clear-column estimate of the water vapor channel is not produced but this is recognized as a simple adjunct to the program--the yield will of course be

_____

[2] In-house memorandum by Dr. Henry Fleming of the National Environmental Satellite Service, NOAA, Department of Commerce, dated September 16, 1976. Information copy sent to MII.

dependent on the local cloudiness characteristics. The fourth disadvantage mentioned is that CLRXN requires about 7 or 8 times as much data processing as do the schemes that NESS has been using for this Component in their job stream. This processing cost, supplemental to the costs of all other related components of the satellite and ground processing systems, must be weighed against the additional, and potential, yields of information.

Another item that is apparent in the NESS evaluation is that the errors in the clear-column radiance components diagnosed by CLRXN tend to be negative; that is, the results favor lowering the correct radiance values. The diagnosed results are consistent with the associated weights, and there is no way to interpret this error inclination as a calibration bias. We now believe this bias to be due to the diagnostic model as applied in both CLRX and CLRXN: The cloud structure is interpreted as being composed, locally, of cloud having broken tops at only one level in the atmosphere and that in the breaks the atmosphere is clear. Although this diagnosed information is weighted according to assessed model conformance the diagnosed adjustment axis is imposed on the whole set of radiances. Disparities due to more complex cloud structures generally bias the results in the negative direction.

All of the above considerations have been addressed in the present project. The new version of the diagnostic model processes a block of scanlines in each application. The name CLRBLOK seemed appropriate. The major improvements and refinements are listed in Section 4.1.

### 1.2.3   The Development of Blending by Weighted Spreading

The major arena in which the Fields by Information Blending (FIB) methodology was conceived and advanced has been in our development of objective analysis techniques for a diversity of two-dimensional fields. Other unique contributions have arisen in structure-blending applications and in the subject diagnostic-model developments.  The methodology has a unity which applies to all processing of real information.

Since the development of CLRXN, MII has produced a new analysis capability designed for the horizontal distribution of atmospheric upper-air parameters, reported by Holl (1976b).  In the course of this work we discovered an advancement which is of major significance for the solution of equations by the method of successive approximations.  The new method is specific to the blending component of all applications of the FIB methodology.  We refer to this new method as Blending by Weighted Spreading (BWS).

The BWS method is characterized by the association of a weight with each successive approximation of each element of the developing solution.  This weight is an absolute measure of the proportion of the total due influence that has arrived at that element.  It is not a measure of the firmness of the solution at that point in the iterations, for further influence may subsequently arrive to substantially alter the developing value. However when the iterations are performed successively, in orderings which alternate direction in each successive pass, most of the due influence is felt in only a few passes.

The BWS method does not make use of any first-guess estimate to the solution for the purpose of initiating the successive approximations. The initiation stems entirely from whatever absolute estimates have been assembled at one or more elements.  Hence there is no bias introduced

into the solution; characteristic components of such biases can linger even after many iterations using Successive Over-Relaxation (SOR) methods. The BWS solution is entirely free of extraneous error at every stage of the iterations.

Although weighted spreading ultimately approaches the exact solution asymptotically, the initial iterations are amazingly effective in gathering information, when using successive alternating-direction orderings. The new diagnostic model, CLRBLOK, introduces a further refinement which exploits the best features of both methods, BWS and SOR. The iterations begin with the BWS method. Then, wherever and whenever the accruing influence weight of an element passes a specified threshold, the algorithm shifts into an SOR iteration for that element. As the influence weights approach unity they become a redundant burden in the calculations; they are then dropped for advanced elements and an over-relaxation factor is introduced.

It is the effectiveness and speed of the BWS/SOR scheme which makes it feasible to expand the capabilities of the new diagnostic model, CLRBLOK, for greater information yield in quality and quantity.

## 1.3    The Diagnostic Model

### 1.3.1    The Ideal

The atmospheric conditions that are most amenable to resolution of clear-column radiance components--by diagnosis of suitable radiance measurements from space--are, of course, local regions that are cloud free. But, in addition to being cloud free, the atmospheric thermal structure should have low spatial variance; this is necessary for assessing that the region is indeed relatively cloud free.

The most amenable of the cloud conditions begins with a scattered-to-broken cloud layer having a uniform top at one distinct level. This level is best positioned in the midst of the several channel source functions of the satellite multi-channel sensor. The scale of the cloud pattern (i.e., the dimensions of the clouds and the clear breaks) should be small compared to the scale of the spatial variability of the clear-column and the cloud-top radiance components. We refer to this situation as a two-state mix of radiance components.

The next most amenable of cloud conditions is a local region in which there are two distinct-and-steady, scattered-to-broken, cloud-top levels--a three-state mix of radiance components.

Theoretically the tractability extends to more-than-two cloud-top levels, but as the cloud structure becomes more complex the required conditions, of distinct and steady radiance components, are rarely to be found in the atmosphere.

The satellite sensing system which is necessary for the resolution of these ideal atmospheric conditions is one which measures the radiances in distinct channels, in each field of view. The more channels the better, and the scanning geometry must produce a high space-and-time density of multi-channel views--dense in comparison to the spatial variability of the individual radiance components. The channel source functions may overlap in the clear atmospheric column, but they should be different from one another to the extent allowable by the number of channels. The individual multi-channel views (i.e., spots) may partially overlap one another but the spots should be small compared to the spatial variability of the individual radiance components.

Given an adequate set of channels, denoted by V in number of channels, and an adequate sample of views in a small region, then the specific mathematical procedure for analyzing the local cloud structure is Factor Analysis. Many meteorologists are familiar with Lorenz's use (1956) of Factor Analysis to define his Empirical Orthogonal Functions. [Psychologists, in particular, are more familiar with the Factor Analysis terminology.] Factor Analysis has also spread into many other contexts in Meteorology.

Factor Analysis assesses the variability of the sample in terms of orthogonal axes in V space, and determines the sample variance which is explained by each axis or combination of axes. A sample with low variance implies a cloud-free structure or a clear structure above a uniform solid overcast. If one axis (i.e., factor) effectively explains most of the sample variance then the interpretation is two state: Each vector of the sample (i.e., each spot of V radiances) lies close to a line in V space. The two radiance components--clear and (presumed) cloud free--bracket all the measured mixes. If two axis (i.e., factors) effectively explain most of the sample variance then the interpretation is three state: All vectors of the sample lie close to a plane defined by the two axes in V space. The orientations of the two axes within this plane are irrelevant. The three radiance components define the corners of the triangle in which all mixes fall.

In interpreting a two-state or a three-state mix, the residual variances are a measure of the difference between the actual cloud structure and the assumed diagnostic state. The weights to be placed on components of the adjustment axis or adjustment plane are related to these residual variances.

The diagnostic model basically consists of diagnosing inherent elements of information for each spot, and of blending these elements for the resultant determination of the clear-column radiance components for all channels of the continuum of spots.

The information produced by Factor Analysis includes the assessment that some measured radiances may be cloud free. This is based on the determination of very low variance for channels in the ambience of the spot. The subset of channels which are assessed as possibly being cloud free for any single spot must be mutually consistent with the distribution of their atmospheric source functions. This consistency requirement should be exploited in the diagnosis of the information elements.

The condition which enables the blending of all diagnosed information elements into a continuum is that the atmospheric thermal-structure has a high degree of horizontal continuity in the object scale of resolution. The diagnostic model imposes a degree of continuity on the clear-column atmospheric radiance components from spot to spot. The degree of validity of this continuity imposition can be enhanced by pre-processing the measured radiances before diagnosis. These preprocessing components also enhance the cloud-structure diagnosis.

The efficacy of remote sensing for atmospheric thermal-structure resolution is thus based on processing large quantities of measurements of channel radiances. The CLRX processing objective is to reduce this data in volume, distilling out the inherent resolution of the clear-column radiance components in the objective scale. The diagnostic model assumes that each spot, of a cluster of spots viewed in a limited cloudy region, is a different mix of distinct and steady radiance components ranging anywhere from clear to overcast in any one view. "Distinct" implies that the model compliance is good. "Steady" implies that the spatial variability of the radiance

components is small compared to the spot-to-spot variabilities. Not much can be done to directly enhance the desired condition of distinctness. But the desired condition of steadiness can be enhanced by implicit reduction of all variances which are extraneous to the cloud-mix contrast from the measured radiances prior to model diagnosis. We refer to these operations which are intended to enhance the cloud-proportion contrast between spots in proximity as the pre-processing components of CLRBLOK.

### 1.3.2 Limitations of the SSE/DMSP System

Figure 1 is an example of the scan pattern of the SSE/DMSP system. Obviously the spots are much too sparse to warrant diagnosis of cloud characteristics, local to each spot, by Factor Analysis. The spot density is not adequate for anything more than a limited two-state interpretation of the cloud structures. Much preprocessing and many special provisions are required to distill the inherent clear-column resolution from the measured radiances.

Another limitation of the data is the limited significance given for each measured radiance. The significance is limited by the number of bits in transmission, and the rounding following calibration of each scanline. Such a system characteristic may be due to an engineering tendency to limit data to _absolute_ significance--not appreciating the possible values of _relative_ information, such as spot-to-spot differences in the present context.

The diagnosis components of models CLRX and CLRXN attempt no more than a two-state interpretation for each spot of the scanline. However, imposition of a two-state interpretation on a full set of atmospheric channels, even though the adjustment-axis components are individually weighted, is accompanied by characteristic errors when the cloud structure is more complex. On the average these errors appear to negatively bias the deeper components of the diagnosed clear-column radiances.

We have introduced a refinement in CLRBLOK which we feel should result in a significant increase in the information yield. The imposition of the two-state interpretation is <u>depth limited</u>, to the optimum validity of the interpretation. The diagnosis makes use of the monotonic character and ordering of the channels according to the depth focus of their atmospheric source functions.

Following preprocessing, channel subsets--subset 1,2,3, subset 1,2,3,4, subset 1,2,3,4,5, and subset 1,2,3,4,5,6--are each assessed for their local degree of compliance with a two-state interpretation. At each spot the optimum subset for that spot is selected. The components of the adjustment axis are then calculated only for this subset. If the optimum atmospheric subset extends to include channel 6--implying that the whole atmospheric column is amenable to two-state interpretation-- then adjunct adjustment-axis components are also calculated for channels 7 and 8 of that spot. The weight for each calculated axis component is calculated according to the local variances of the respective-channel component.

Any clear-column radiance components produced for channels 7 and 8 should be considered to be byproducts of the CLRBLOK diagnosis. Their reliability is subject to additional considerations: In addition to being dependent on the resolution extending to channel 6, the accuracy also depends on the spot-to-spot channel uniformity of the diagnosed clear-column radiances for each of these channels: Each component of the adjustment axis is based on the assumption that local spot-to-spot differences are due only to differences in the cloud proportion of each spot.

-14-

## 1.4     The CLRBLOK Model

### 1.4.1   The Preprocessing Components

#### 1.4.1.1   Purposes

The primary purpose of the preprocessing components is to implicitly reduce all variations inherent in the measured radiances which are extraneous to the diagnostic model--extraneous to the assumption that local spot-to-spot radiance differences are largely due to differences in cloud amount.  This assumption is basic to the assessment of clear-column radiances, to the diagnosis of the local adjustment axis, and to imposition, in the total information blending, of a degree of horizontal continuity for the clear-column atmospheric radiance components.  These CLRBLOK refinements extend applicability into regions where surface-temperature variability is pronounced, enabling information yield for the atmospheric components of the clear-column radiances.  Additional benefits are indicated in Section 1.4.1.4 below.

#### 1.4.1.2   Local Standard Atmospheres and Transforms

Nineteen standard pressure levels are provided for specification of first-guess temperature profiles: 0, 4, 7, 10, 20, 30, 50, 70, 100, 150, 200, 250, 300, 400, 500, 700, 850, 925, and 1000 mb.  The temperatures specified for these levels are subscripted 1 through 19 respectively; subscript 20 refers to the surface temperature.  The temperature profile is specified to be linear in $p^\kappa$, where $\kappa \equiv 2/7$.

First-guess temperature profiles are interpolated from available isobaric temperature fields for every 3rd spot of each scanline; this data includes the central spot numbered 13.  Temperatures for levels not now routinely available are generated by linear-in-$p^\kappa$ for $T5$ and $T7$, and by setting $T_1$, $T_2$ and $T_3$ equal to $T_4$.  Sea-surface temperatures are

interpolated from available analyses for all spots. These interpolations involve special FNWC subroutines (see Section 3.2).

A standard atmosphere is defined for each scanline--the first-guess temperature profile for spot 13. These standard profiles are generally continuous from scanline to scanline.

The available transmission functions are required only for zenith-angle zero degrees and zenith-angle thirty degrees. These transmission-function tables are expanded by interpolation to include all the standard pressure levels listed above. Standard radiances are calculated for each channel of each scanline for each of the two zenith angles.

Based on a linearization of the Planck function about the standard-atmosphere temperatures at each pressure level, transformations are calculated which express the radiance anomaly for any channel, $v$, and zenith angle 0 or 30 degrees, as a linear combination of the standard-profile temperature anomalies, including the surface-anomaly contribution. Several additional parameters are calculated for each channel for each of the two zenith angles: a _mean_ pressure level for the atmospheric source function, and a normalizing factor for converting each radiance anomaly into units of temperature anomaly. The relevant formulations for these transformations were detailed in Holl (1973a) and again appeared in Holl (1975a, 1975b and 1976a).

Standard-atmosphere values, the anomaly-transform coefficients, atmospheric-source pressure levels, and temperature-normalization factors are calculated only for the zenith angles of zero degrees and thirty degrees. Preprocessing components calculate corresponding values for the spot zenith angles, by linear interpolation or extrapolation in terms of an optical path-length equivalence.

### 1.4.1.3  Component Operations

All measured radiances are first reduced to anomalies from local standard clear-column radiances, defined for each scanline, including zenith-angle dependence.  Three operations which act implicitly[3] on the clear-column radiance components follow:  Removal of the surface contribution from all measured radiances for those channels which penetrate to the surface in clear conditions, by proportional subtraction of the measured window radiances; normalization of the radiance anomalies into temperature-anomaly units; and nadir normalization.  Nadir normalization modifies the temperature-normalized atmospheric radiance anomalies by interpolation (downward extrapolation in the case of channel 6) between associated source-function pressure-reference levels at spot zenith angle, to the corresponding pressure-reference level at zero zenith angle.

These operations are followed by subtraction of calculated independent (i.e., first-guess) temperature-normalized nadir-normalized radiance anomalies from standard.

The first-guess radiances are calculated using only the required zero-zenith-angle transformations.  The independent temperature-profile anomalies, obtained for every third spot of each scanline, are transformed into calculated radiance anomalies, and these are linearly interpolated for the in-between spots.

---

[3] Each measured radiance is a sum of clear-column and cloud-top components.  An _implicit_ operation forms linear combinations of measured channel radiances all of one spot, in order to effect implicit adjustments of the inherent clear-column components.  Corresponding adjustments take place in the cloud-top components.

-17-

Subtraction of these calculated first-guess radiances reduces another of the variances which are extraneous to the diagnostic model--the spatial spot-to-spot variability of the inherent clear-column radiance components. CLRBLOK also includes provisions to exploit these calculated independent radiance estimates in the diagnosis components of Part 2.

### 1.4.1.4 Reversibility

All of the preprocessing components are derived from transformations, developed between each clear-column radiance and the temperature profile, based on available transmission functions. Accuracy is, of course, desirable to make the preprocessing components as effective as possible in the subsequent diagnosis. However the errors introduced thereby are not of primary concern: The preprocessing components can be reversed after diagnosis of the clear-column radiance components. Reversals are performed in the restoration components of CLRBLOK, with the exception of two operations:

(i) The diagnosed clear-column radiance components are left nadir normalized. This improves utility. Channel calibration errors have only a second-order effect on these adjustments.

(ii) The surface contributions are not restored to the atmospheric channels. The diagnosed clear-column window radiances are generally not as reliable as the diagnosed and weighted clear-column atmospheric-component radiances. The diagnosed atmospheric components should be calibrated and exploited directly for use in atmospheric thermal-structure resolution enhancement.

### 1.4.1.5 The Preprocessed Radiances

The preprocessing components transform the measured radiance of channels 1 through 6, into a corresponding matrix of values, in several component operations: anomalies from local standard radiances, implicit atmospheric component of the clear-column component, temperature normalized equivalent units, implicitly nadir-normalized clear-column components, anomalies from the corresponding independent calculated (i.e., first-guess) equivalent quantities. The measured channel 7 radiances are transformed into temperature-normalized anomalies from the first-guess surface temperatures. The measured channel 8 radiances are unchanged by the preprocessing components.

This three-dimensional matrix of values, V channels, N spots and M scanlines, is passed on to Part 2: The Diagnosis Components. The corresponding independent first-guess estimates of the clear-column components are zero by definition for channels 1 through 7.

The calculated independent (i.e., first-guess) radiances and all other quantities required for reverse transformation of the clear-column components diagnosed by Part 2 are saved for use in Part 3: The Restoration Components.

No matrix of associated weights is attached to the calculated first-guess radiance estimates. Such associated weights are dependent on the variances inherent in the analyzed temperature fields, in the interpolation to spot locations in space and time, and in the transformation coefficients which in turn are dependent on the accuracy of the available transmission functions. Instead, when exploited, associated weights are estimated and specified only as function of channel number and cycle[4] number.

---

[4]The diagnosis and blending components are repeated three times, defining three cycles, in order to purify and refine the weighting of the diagnosed information elements.

1.4.2 The Information Diagnosis and Blending Components

1.4.2.1 Diagnosis and Blending in Terms of Adjustment Values

The diagnosis and blending components are formulated in terms of adjustments, $\mathcal{O}_{v,n,m}$ , that are to be added to the preprocessed radiances, $E_{v,n,m}$ , to produce the equivalent clear-column radiance components. The subscripts refer to channel number, spot number, and scanline number, respectively.

As is the practice in most FIB methodology applications, CLRBLOK includes the standard optimum number of three cycles through the information diagnosis and blending components. Three cycles allow for an initial, and two progressively more stringent evaluations of individual information elements. The notation of denoting the resultant values of the blending of all assembled information by a superscript asterisk is also standard. After each cycle of diagnosis and blending the resultant adjustment values are added to the preprocessed radiances to produce the resultant clear-column radiance equivalents:

$$E_{v,n,m}^{+} \equiv E_{v,n,m} + \mathcal{O}_{v,n,m}^{*} \quad . \tag{1}$$

To begin with, the only estimates that are available for comparitive evaluations of diagnosed information elements are the independent first-guess estimates. These translate into the adjustment estimates

$$\mathcal{O}_{v,n,m} = -E_{v,n,m} \quad . \tag{2}$$

But each subsequent blending operation produces new estimates--more reliable and hence more effective for comparitive evaluations in the diagnosis component of the following cycle.

### 1.4.2.2 The Diagnosed Information Elements

Three types of information elements are diagnosed, assembled, and imposed in the subsequent blending:

(i) Absolute Estimates.

Tentative weights, $A^e_{v,n,m}$, are assigned to those radiances which are assessed to be cloud free on the basis of local variances in measured radiances. The associated adjustment estimate is $\varphi_{v,n,m} = 0$.

These information elements are assembled with the independent first-guess estimates, $- E_{v,n,m}$, which are given the weights $A^{(c)}_{v,n,m}$. The superscript c in parentheses denotes cycle number. The resultants of this assembly are given by:

$$\varphi_{v,n,m} = \frac{- A^{(c)}_{v,n,m} \quad E_{v,n,m}}{A^{(c)}_{v,n,m} + A^e_{v,n,m}} \tag{3}$$

$$A_{v,n,m} = A^{(c)}_{v,n,m} + A^e_{v,n,m} \tag{4}$$

The tentative weights, $A^e_{v,n,m}$, are reassessed in each cycle, making use of the first-guess information in cycle one, and of the preceding blended resultants in cycles two and three.

The weights given to the first-guess estimates should be low in cycle one because of calibration uncertainties and because the estimates are not independent from channel-to-channel and spot-to-spot. The weights are reduced further in cycle two, and are made negligible in cycle three in order to leave the final resultants free of any direct contributions from the first-guess estimates. The first-guess information is exploited primarily for and in the diagnosis of information elements inherent in the measured

radiances, as for example in situations where ambient channel variances are low not because the region is cloud free but because of a solid uniform cloud top.

(ii) Adjustment Axes.

A weighted set of difference vectors is formed for each spot $n, \pi$, by differencing its set of measured radiances with those of six ambient spots-- four on the same scanline and the corresponding two spots from adjoining scanlines. The best available adjustment vector for the spot forms a seventh vector, suitably weighted according to cycle number.

The coherence of these seven vectors is evaluated in subsets of channels: 1,2,3; 1,2,3,4; 1,2,3,4,5; and 1,2,3,4,5,6. The subset of best coherence, if the best is deemed adequate, is then combined to form a single adjustment axis of that many channel components. Component weights are calculated, based on variances within the relevant subset and local sample of difference vectors. If the optimum subset includes channel 6, then adjustment components are also formed and weighted for channels 7 and 8.

(iii) Horizontal Continuity

The spot-to-spot continuity in the clear-column radiance components implies that there is little difference in the resultant, $E_{v,n,\pi} + \mathcal{O}^{*}_{v,n,\pi}$, between spots adjoining in a scanline and adjoining between scanlines. The corresponding weights assigned to these general information statements are specified to be largest in cycle one, thus forcing the first blending resultant to produce a larger objective scale of resolution. Although representative of a larger scale than the final objective, the first-cycle resultants are relatively more reliable and hence are useful in evaluating information elements in cycle two. The subject continuity weights are reduced in the cycle-two blending, and again in cycle three to allow the desired inherent scale of resolution to emerge.

### 1.4.2.3 The Blending Operation

In each cycle all assembled and weighted information elements are blended to produce the optimum resultant adjustment field, $\sigma_{v,n,m}$. This resultant minimizes the associated error functional of the information system. Minimization amounts to solution of the associated system of simultaneous equations:

$$\underset{\approx}{M} \, \underset{\sim}{\sigma}^* = \underset{\sim}{F} \tag{5}$$

where the solution vector $\underset{\sim}{\sigma}^*$ and the forcing vector $\underset{\sim}{F}$ have an element for each radiance. The matrix $\underset{\approx}{M}$ is symmetric, positive definite; its elements are formed entirely from information weights.

The solution is developed by the method of Blending by Weighted Spreading (BWS) shifting to Successive Over Relaxation (SOR) whenever and wherever the blending weight approaches one for any element of the $v, n, m$ array.

### 1.4.2.4 The Associated Resolution Weights

Associated resolution weights, $A^*_{v,n,m}$, are required for the final resultant clear-column estimates, $\sigma^*_{v,n,m}$, produced by the third cycle of blending. According to the FIB methodology the associated weights appear, inverted, as the diagonal elements of the inverse of matrix $\underset{\approx}{M}$ of Eq. (5).

Very little continuity coupling is imposed between scanlines in cycle three. Hence reasonable approximations of reliability can be calculated for each scanline by inverting only the coefficient matrix for that scanline.

### 1.4.3  The Restoration Components

The restoration components simply reverse corresponding operations of the preprocessing, with the exceptions already mentioned in Section 1.4.1.3.  The reversals are performed explicitly in terms of the diagnosed clear-column components.

### 1.5    Thermal-Structure Blending

We have appended a Thermal-Structure-Blending (TSB) capability to the CLRBLOK job stream in order to present a more complete functional capability.  This version demonstrates how efficiently the relevant information in clear-column-radiance estimates can be used to directly enhance the resolution of the atmospheric thermal-structure.

The TSB capability is less comprehensive than is the mass-structure blending scheme, named STRBLND, mentioned in Section 1.2.1.  STRBLND involves more than the thermal profile; included are provisions for height estimates of pressure levels.


It should be noted at the outset of this discussion that there is a reversal of objectives between CLRBLOK and TSB.  Relationships between channel radiances and the thermal profile are exploited in both schemes.  In the case of CLRBLOK the relationships are used to exploit information concerning the thermal-structure for its relevance to the clear-column radiance resolutions, and in the case of TSB the relationships are used to exploit information concerning the clear-column radiances for its relevance to the thermal-structure resolution.

In CLRBLOK the objective is maximum resolution of the clear-column radiances. In TSB the objective is maximum resolution of every element of the thermal-structure model. [The thermal-structure model is that described in paragraph 1 of Section 1.4.1.2.] The same linearized approximations are used to express relevant independent (i.e., first-guess) estimates.[5] Both applications of information blending must be carried out to effect both objectives. The end results are not equivalent. Appreciation of the difference is essential to the understanding of how the FIB methodology derives maximum _relevance_ from available information.

Relating a clear-column radiance-anomaly estimate to a linear combination of the temperature-anomaly elements of the thermal-structure profile model involves two contributing error variances: the error variance associated with the diagnosed clear-column radiance, and the error variance inherent in the form of the linearized anomaly relationship.

In order to demonstrate the TSB capability we have used the sets of linear-transform combination coefficients which are computed by preprocessing component C1.1 for scanline 5 of the development sample (see Sections 2.1 and 2.2). The diagnosed clear-column radiance weights are reduced rather sharply by addition of large estimates of the variances attributed to the transforms.

A subroutine is required[6] for introduction into the CLRBLOK job stream. Its function would be to replace the available standard coefficients by

---

[5] In CLRBLOK we choose to minimize the direct contribution of the calculated clear-column radiances in the diagnosed resultant clear-column radiances, in order to use these diagnosed radiances as _independent_ satellite information for subsequent enhancement of the thermal-structure profile.

[6] This requirement is included among our recommendations (see Section 4.)

coefficients which are optimized for the local conditions. These transformations should be statistically refined in order to minimize the associated error variances.

The thermal-structure-blending capability includes the following features:

The blending is performed in terms of potential-temperature values for the standard pressure levels. The independent temperature estimates, $T_i$, and associated weights, $A_i$, are transformed accordingly.

The clear-column radiance estimates are transformed into estimates of linear combinations of the potential-temperature values. The weights associated with these estimates are reduced in accordance with contributing error variances ascribed to the relationship for each of the six atmospheric channels.

The blended solution, $\theta_i^*$, and associated resolution weights, $A_i^*$, are calculated by explicit matrix inversion.

The solution profile is tested to be statically stable: It is required that the potential-temperature values decrease from one standard pressure level to the next, beginning at the top of the atmospheric column. If any level fails the static-stability test, because the potential-temperature value is found to be greater than that for the level just above, then the value is replaced by that for the level just above. This procedure is followed sequentially from top to bottom. The adjusted solution is then optimized, within the constraint of positive static stability, by sequential SOR passes from top to bottom. This procedure exploits the additional information that the atmosphere is statically stable in the object scale of resolution.

The potential-temperature values of the solution are transformed into temperature values, $T_i^*$. The associated resolution weights are transformed accordingly.

Independent, first-guess, temperature profiles are obtained for use in CLRBLOK for every third spot of each scanline. The Thermal-Structure Blending (TSB) capability is programmed to process this subset of spots excluding spots 1 and 25 of each scanline.[7] The Sample run (see Section 2), which includes TSB applications for 63 profiles has demonstrated the efficiency and effectiveness of this capability.

---

[7]Clear-column radiances are not diagnosed for spots numbered 1, 2, 24 and 25 of each scanline because of the sparsity of spots in scanline extremes, and for convenience in avoiding boundary complications in the programming.

2.      DEVELOPMENT OF THE JOB STREAM

2.1     Component Operations of the Job Stream

Part 1: The Preprocessing Components

     C1.0    Initialization

     C1.1    Generation of Standard Profile Transforms

     C1.2    Local Standard Radiances, and Anomalies from Standard

     C1.3    Implicit Removal of Surface Contribution

     C1.4    Implicit Temperature Normalization

     C1.5    Implicit Nadir Normalization

     C1.6    First-Guess Radiance

     C1.7    Optional Linear Transformation of Atmospheric Channels
            (not presently used)

     C1.8    Subtraction of First-Guess

     C1.9    Organization of Scanline into Block Format

     C1.10   Save Labeled Common Blocks for Later Use

Part 2: The Diagnostic Components

     C2.0    Initialization

     C2.1    Ambient Variance in Preprocessed Radiances

     C2.2    Adjustment Axis Estimates for Each Spot

            C2.2.1   Initialization

            C2.2.2   Local Contrast Vectors

            C2.2.3   Optimum Depth of Model Endorsement

Part 4: Thermal-Structure Blending Components

      C4.1   Initialization

      C4.2   Refinements of Coefficients and Specifications
              (Provision for future subroutine)

      C4.3   Estimate and Weight Transformation

      C4.4   Explicit Blending Solution

            C4.4.1   Fill Blending Matrix

            C4.4.2   Invert Matrix

            C4.4.3   Form Forcing Vector

            C4.4.4   Resultant Profile $\theta^{*}$

            C4.4.5   Associated Resolution Weights

      C4.5   Stabilize the Profile

            C4.5.1   Test and Adjust Profile

            C4.5.2   Optimize Adjustments

      C4.6   Organize Resultant, $E^{**}$

## 2.2   Print Options

The CLRBLOK job stream has been designed to include a wide choice
of printout options to aid in the initial program debugging, in developing
familiarization with component functions, and for evaluating program
modifications and tuning adjustments.

The amount of printed output can be varied for each scan and/or block of scans:

### All Sections:

> Numerical values for each scan, and the block, are stored in array MOPT(20), located in Labeled Common Block PARBL. These values range from 1 (for complete print-out) to $\geqq 8$ (no print-out).

> $MOPT_1 \ldots MOPT_9$ contain print options for scan #1...#9.

> $MOPT_{10}$ contains print option for the whole block.

> MO is generally = the current print option.

### Sections 4.3...4.6:

> If $MO \leqq 3$, then any profile spot can be selected for detailed print-out.

> Print option values are stored in arrays MONP(7), MOM(9), and MONPM(7,9) in Section 4.0.

> These details are covered in C4.1 (Initialization) of the Program Documentation.

The lists of Common Blocks, arrays, and other values with their accompanying print options are included in the functional description.

## 2.3   The Development Sample

The sample block of nine scanlines shown in Figure 1 was used as the development sample for program CLRBLOK. This sample block was selected from the available collection of radiances because it was the longest continuous sequence of scanlines over open ocean. The block was not selected with any particular expectations as to yield, nor were the cloud characteristics considered in the selection.

The information yield which is expressed by the reliability weights of the diagnosed clear-column radiances is dependent on the characteristics of the cloudiness. A clear region generally gives the highest yield. The CLRBLOK capability is designed to diagnose the inherent information in the measured radiances no matter how great or how meager that yield might be. It is even more important that false information not be generated and assimilated than it is that good information be produced.

## 2.4   Preliminary Components

The input requirements for Program CLRBLOK include:

(a)  The measured radiances organized by channels, spots and scanlines, with spot locations, zenith angles and timing data.

(b)  Estimates of the temperature profiles for every third spot of each scanline. Each profile is expressed by the temperature ($^\circ$K) at each of 19 standard pressure levels.

(c)  Estimates of the sea-surface temperature for each spot, and a land/sea delta-function (i.e., 0 or 1) value for each spot.

(d)  Transmission functions for each channel for zenith angles $0^\circ$ and $30^\circ$. These functions are used in Part 1 (subroutine RADCOF) for theoretical calculation of the transforms used in calculating independent first-guess

-32-

radiances, and are used in Part 4 in thermal-structure blending.  We consider this dependency on theoretical transmission functions to be an interim necessity, awaiting replacement by superior means.

In an operational context the required input would pass through the processing center in a lagged real-time mode.  For present development purposes the above data was assembled by R&D procedures.  These procedures have been designated Part 0 of Program CLRBLOK, but they should not be considered part of the job stream.  The input preparations for CLRBLOK, in an operational context, will depend on the specifics of the operating system.

## 2.5    The Sample Performance

The yield derived from the sample block of scanlines turned out to be high for channels 1, 2 and 3, effectively nil for channels 6, 7 and 8, and intermediate, and spotty, for channels 4 and 5, all according to the product associated reliability weights.  This untuned diagnosis by CLRBLOK implies that the region has a complex cloud structure above a low overcast. The complex cloudiness has been confirmed by examination of the concurrent synoptic data.  Figure 2 is a surface analysis with station-model plots. The four stars in Fig. 2 indicate the corner points of the quasi-rectangular region covered by the nine scanlines.  Considering the synoptic situation, the atmospheric depth of model relevance and the resulting information yield of the CLRBLOK diagnosis are understandable.  The model performed according to performance expectations.
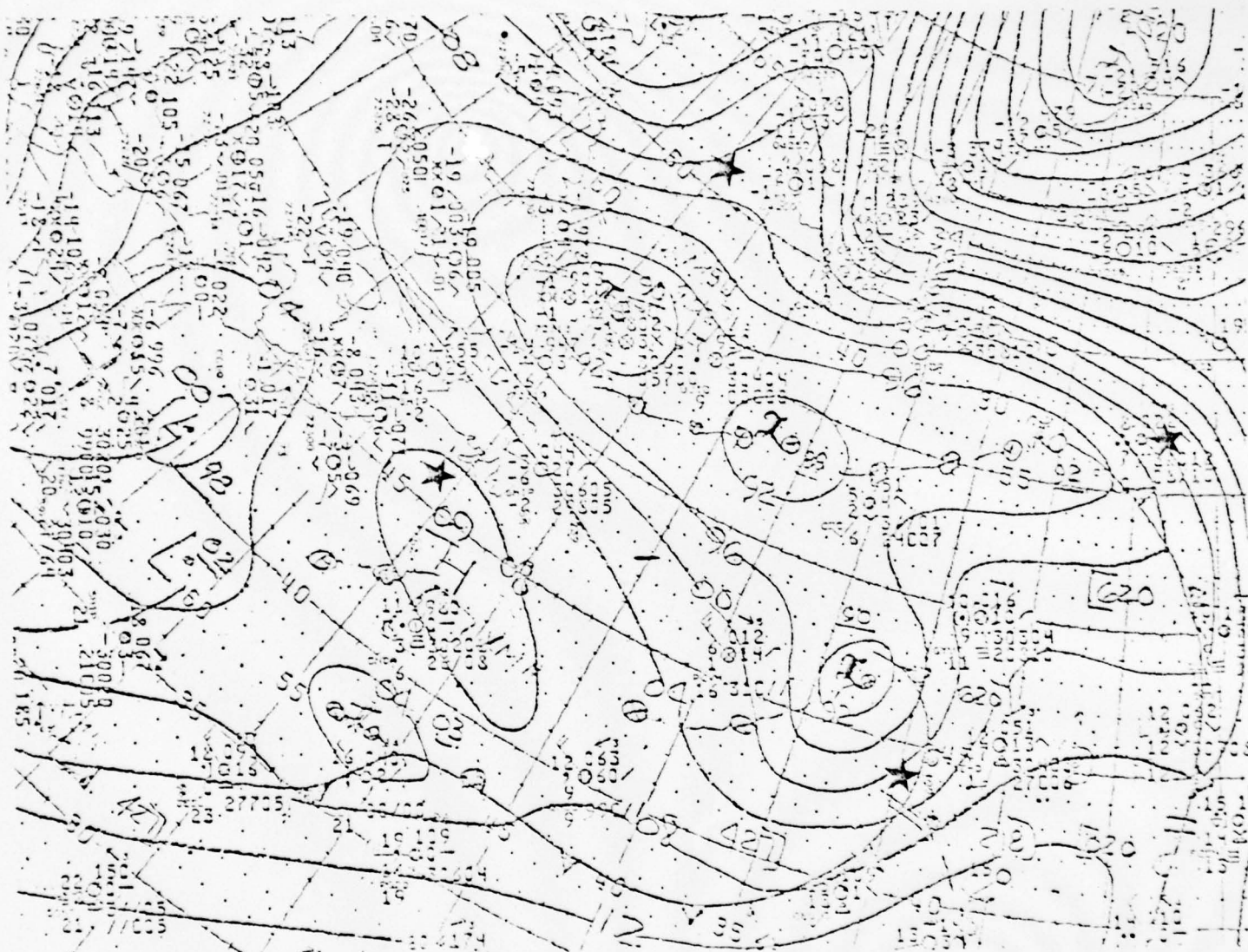
Fig. 2   Surface Analysis with Station Model Plots for 7701170OZ.

## 2.6    Program Timings

The following timing figures were determined for the CLRBLOK job stream, including the thermal-structure-blending supplement in CLRBL3. These figures, in CP seconds of execution time, apply to the processing of the sample block of nine scanlines, using FNWC's R&D CDC-6500 computer named "HAL".

|  | With Printout (as delivered) | Without Printout but including all print decision steps |
|---|---|---|
| CLRBL1 | 16.541 | 2.190 |
| CLRBL2 | 188.918 | 168.652 |
| CLRBL3 | 22.999 | 17.091 |
| Total | 228.458 | 187.933 |

Removal of all print provisions would make a significant reduction in the length of the program listing--about a 30% reduction.

## 2.7    Program Documentation

An extensive program documentation of the CLRBLOK job stream, including the preliminary components and the thermal-structure-blending capability supplement, has been prepared and assembled under separate cover. This volume of documentation includes the following material:

General flow diagrams showing structure of complete job stream, processing programs, and accompanying subroutines.

Detailed functional description of complete job stream:
Preliminary Components, Preprocessing Components, Diagnosis
Components, and Restoration and Thermal-Structure Blending
Components.

Control card listings for each job-stream unit are included in the
functional description, as well as in each file listing.

Detailed common block definitions.

Subroutine calls, and parameters used.

Print Options.

Program listings and the sample production run (including compilation
and execution printouts) have also been delivered to the sponsoring agency
(NEPRF).

3.    FORMULATIONS

3.1    Developments of the Blending System

3.1.1   The Functional and the System of Blending Equations

Applications of the Fields by Information Blending (FIB) methodology begin with the design of the functional--with the design of provisions in the functional to include the various available relevant forms of information. The functional includes various elements of information, and these elements with their associated weights serve as repositories for the assembly of information gathered in forms of weighted estimates. The CLRX, CLRXN, and CLRBLOK functionals include a form of information which is unique in FIB applications: the components of adjustment axes for subset vectors of the object array. The functional expresses the sum of the weighted squared-disparities to all assembled elements:

$$
\begin{aligned}
F \equiv \sum_{v,n,\pi} \Big\{ & A_{v,n,\pi} \left( c^*_{v,n,\pi} - c_{v,n,\pi} \right)^2 \\
& + B_{v,n,\pi} \left( c^*_{v,n+1,\pi} + E_{v,n+1,\pi} - c^*_{v,n,\pi} - E_{v,n,\pi} \right)^2 \\
& + C_{v,n,\pi} \left( c^*_{v,n,\pi+1} + E_{v,n,\pi+1} - c^*_{v,n,\pi} - E_{v,n,\pi} \right)^2 \\
& + W_{v,n,\pi} \left( c^*_{v,n,\pi} - L_{n,\pi} K_{v,n,\pi} \right)^2 \Big\} \quad .
\end{aligned}
\tag{6}
$$

Notation:

The subscripts $v, n, m$ refer to the channel, spot, and scanline number respectively. The summation extends over the entire block of scanlines.

$O^*_{v,n,m}$    is the object adjustment that is to be added to the preprocessed radiance, $E_{v,n,m}$, to produce the equivalent clear-column radiance components, $O^*_{v,n,m} + E_{v,n,m}$, for channel $v$ of spot $n$ of scanline $m$.

$O_{v,n,m}$    is the assembled direct estimate of $O^*_{v,n,m}$ and $A_{v,n,m}$ is its weight.

$B_{v,n,m}$    is the weight of the estimate that there is zero difference between the clear components of spots $v, n, m$ and $v, n+1, m$.

$C_{v,n,m}$    is the weight of the estimate that there is zero difference between the clear components of spots $v, n, m$ and $v, n, m+1$.

$K_{v,n,m}$    is the $v$ component of the adjustment-axis estimate at the $n, m$ spot.

$L_{n,m}$    is the unknown length factor of the adjustment-axis estimate at the $n, m$ spot.

$W_{v,n,m}$    is the weight corresponding to the $L_{n,m} K_{v,n,m}$ adjustment estimate.

The object solution--the array of $c^*_{v,n,m}$ --is that set of values which minimizes the functional, $F$. The length factors, $L_{n,m}$, are also determined by minimization of the functional, $F$.

Setting $\partial F/\partial c^*_{v,n,m} = 0$ yields the arbitrary-component equation of the simultaneous system of equations:

$$A_{v,n,m}\left(c^*_{v,n,m} - c_{v,n,m}\right)$$

$$- B_{v,n,m}\left(c^*_{v,n+1,m} + E_{v,n+1,m} - c^*_{v,n,m} - E_{v,n,m}\right)$$

$$+ B_{v,n-1,m}\left(c^*_{v,n,m} + E_{v,n,m} - c^*_{v,n-1,m} - E_{v,n-1,m}\right)$$

$$- C_{v,n,m}\left(c^*_{v,n,m+1} + E_{v,n,m+1} - c^*_{v,n,m} - E_{v,n,m}\right)$$

$$+ C_{v,n,m-1}\left(c^*_{v,n,m} + E_{v,n,m} - c^*_{v,n,m-1} - E_{v,n,m-1}\right)$$

$$+ W_{v,n,m}\left(c^*_{v,n,m} - L_{n,m} K_{v,n,m}\right) = 0 \quad . \tag{7}$$

Setting $\partial F/\partial L_{n,m} = 0$ yields the equation which determines $L_{n,m}$ for the arbitrary $n, m$ spot:

$$L_{n,m} = H_{n,m} \sum_{w} W_{w,n,m} K_{w,n,m} c^*_{w,n,m} \tag{8}$$

where $w$ has been introduced as a dummy subscript for $v$, and where

$$H_{n,m} = \left\{\sum_{w} W_{w,n,m} K^2_{w,n,m}\right\}^{-1} \quad . \tag{9}$$

-39-

Equation (8) is used to eliminate $L_{n,m}$ in Eq. (7). In anticipation of the Blending-by-Weighted-Spreading (BWS) formulation we express the resultant general equation as follows:

$$S_{v,n,m} \cdot \sigma^*_{v,n,m} = A_{v,n,m} \cdot \sigma_{v,n,m}$$

$$+ \; B_{v,n,m} \cdot \left( \sigma^*_{v,n+1,m} + E_{v,n+1,m} - E_{v,n,m} \right)$$

$$+ \; B_{v,n-1,m} \cdot \left( \sigma^*_{v,n-1,m} + E_{v,n-1,m} - E_{v,n,m} \right)$$

$$+ \; C_{v,n,m} \cdot \left( \sigma^*_{v,n,m+1} + E_{v,n,m+1} - E_{v,n,m} \right)$$

$$+ \; C_{v,n,m-1} \cdot \left( \sigma^*_{v,n,m-1} + E_{v,n,m-1} - E_{v,n,m} \right)$$

$$+ \; W_{v,n,m} H_{n,m} \sum_{w \neq v} \left\{ W_{w,n,m} K^2_{w,n,m} \cdot \frac{K_{v,n,m}}{K_{w,n,m}} \sigma^*_{w,n,m} \right\} \tag{10}$$

where

$$S_{v,n,m} \equiv A_{v,n,m} + B_{v,n,m} + B_{v,n-1,m} + C_{v,n,m} + C_{v,n,m-1}$$

$$+ \; W_{v,n,m} - H_{n,m} W^2_{v,n,m} K^2_{v,n,m} \quad . \tag{11}$$

It should be noted that

$$W_{v,n,m} H_{n,m} \sum_{w \neq v} W_{w,n,m} K^2_{w,n,m}$$

$$\equiv \; W_{v,n,m} - H_{n,m} W^2_{v,n,m} K^2_{v,n,m} \quad . \tag{12}$$

-40-

The equation for $S_{v,n,\pi}$, Eq. (11), can be considered to be inherent in Eq. (10). Equation (10) should, first of all, be recognized as a weighted summation of several estimates of the quantity $c^*_{v,n,\pi}$, and $S_{v,n,\pi}$ should be recognized as the sum of the weights. The individual estimates appear to the right of each heavy dot, and the weights are the coefficient factors to the left of each heavy dot. We propose that weighted combinations of estimates be written using the notation of heavy dots to separate individual estimates and their coefficient factors. And we further propose that a second equation is implicitly specified by such notation--the equation obtained by dropping each estimate to the right of each dot, summing only the coefficient weights. According to this notation and convention, Eq. (11) is implicit in Eq. (10).

### 3.1.2 Blending by Weighted Spreading and SOR

The blending system of equations, represented by Eq. (10), is readily cast in the form which defines the Blending by Weighted Spreading (BWS) procedure of solution by successive approximations:

$$
\alpha^{(R+1)}_{v,n,\pi} \bullet c^{(R+1)}_{v,n,\pi} = A_{v,n,\pi} \bullet c_{v,n,\pi}
$$

$$
+ \ B_{v,n,\pi}\, \beta^{(R)}_{v,n+1,\pi} \bullet \left( c^{(R)}_{v,n+1,\pi} + E_{v,n+1,\pi} - E_{v,n,\pi} \right)
$$

$$
+ \ B_{v,n-1,\pi}\, \beta^{(R)}_{v,n-1,\pi} \bullet \left( c^{(R)}_{v,n-1,\pi} + E_{v,n-1,\pi} - E_{v,n,\pi} \right)
$$

$$
+ \ C_{v,n,\pi}\, \beta^{(R)}_{v,n,\pi+1} \bullet \left( c^{(R)}_{v,n,\pi+1} + E_{v,n,\pi+1} - E_{v,n,\pi} \right)
$$

$$
+ \ C_{v,n,\pi-1}\, \beta^{(R)}_{v,n,\pi-1} \bullet \left( c^{(R)}_{v,n,\pi-1} + E_{v,n,\pi-1} - E_{v,n,\pi} \right)
$$

$$
+ \ W_{v,n,\pi}\, H_{n,\pi} \sum_{w \neq v} \left\{ W_{w,n,\pi}\, K^2_{w,n,m}\, \beta^{(R)}_{w,n,\pi} \bullet \frac{K_{v,n,\pi}}{K_{w,n,m}}\, c^{(R)}_{w,n,\pi} \right\} . \quad (13)
$$

-41-

The superscript R , in parentheses, numbers

(i) the successive approximations, $c_{v,n,\pi}^{(R)}$ , obtained toward the desired solutions, $c_{v,n,\pi}^{*}$ , and

(ii) the successive value of a new parameter--the corresponding <u>accrual parameters</u>, $\alpha_{v,n,\pi}^{(R)}$ , which wax toward the total due influence weights, $S_{v,n,\pi}$ .

The corresponding <u>accrual factor</u> is defined by

$$\beta_{v,n,\pi}^{(R)} \equiv \frac{\alpha_{v,n,\pi}^{(R)}}{S_{v,n,\pi}} \quad . \tag{14}$$

It is the measure of the proportion of the total due influence that has been accrued to make the estimate, $c_{v,n,\pi}^{(R)}$ , significant.

The estimates that are combined by Eq. (10)--other than the direct estimate which appears first, but including each estimate which forms a term of the summation--each involve dependency on only one of the elements of $c^{*}$ . In BWS the contribution of each of these estimates is reduced by the accrual factor which corresponds to the significance of the latest estimate for that element of the evolving solution. It follows that, in applying the two equations implied by Eq. (13), to calculate a new approximation $c_{v,n,\pi}^{(R+1)}$ and the associated accrual parameter $\alpha_{v,n,\pi}^{(R+1)}$ , each contributing estimate influences the new approximation only in proportion to its own significance.

Equations (13) are self-initializing beginning with zero values for $\alpha^{(0)}$ and $c^{(0)}$ , but the preferred initialization is to anticipate the results of a single simultaneous pass through the array:

$$\alpha_{v,n,\pi}^{(0)} = A_{v,n,\pi}$$

$$c_{v,n,\pi}^{(0)} = c_{v,n,\pi} \quad . \tag{15}$$

-42-

The iterations are performed sequentially through the full array, immediately entering the new values of both $c^{(R)}$ and $\alpha^{(R)}$ as they are computed for each element. The ordering of each pass through the full array is alternated through a sequence of four different orderings.

It should be apparent that

(i)   the developing solution emanates, or "spreads" out, from all direct estimates $c$ of weights A in the array, to "blend" everywhere in the process,

(ii)   the $\lim\limits_{R \to \infty} \alpha^{(R)}_{v,n,\pi} = S_{v,n,\pi}$

the $\lim\limits_{R \to \infty} \beta^{(R)}_{v,n,\pi} = 1$ ,                                                               (16)

(iii)   wherever $\beta$ approaches its limit, Eq. (13) has effectively reduced to Eq. (10) for that element.

The blending component for solution of the system of equations represented by Eq. (10) exploits the best capabilities of Blending by Weighted Spreading (BWS) and Successive Over Relaxation (SOR). Whenever and whereever the condition has occurred that

$$\beta^{(R)}_{v,n,\pi} \geqq \text{ some prescribed value}$$                                                               (17)

then the blending algorithm shifts from BWS to SOR for that element.

In some portions of the array, especially where direct clear-column estimates are remote such as for deep channels in cloudy regions, the growth of $\beta$ elements can be rather slow in successive BWS passes. In order to

hasten the shift of the blending into the SOR mode, an amplification factor, say 1.1, can be applied to each new calculated $\beta$ element, holding the upper limit at one. With the inclusion of such an amplification factor the prescribed value of Eq. (17) may be set equal to one.

The SOR algorithm for Eq. (10) is expressed by

$$c_{v,n,m}^{(R+1)} = c_{v,n,m}^{(R)} + \Omega \left\{ \left[ A_{v,n,m} \, c_{v,n,m} \right. \right.$$

$$+ \; B_{v,n,m} \left( c_{v,n+1,m}^{(R)} + E_{v,n+1,m} - E_{v,n,m} \right)$$

$$+ \; B_{v,n-1,m} \left( c_{v,n-1,m}^{(R)} + E_{v,n-1,m} - E_{v,n,m} \right)$$

$$+ \; C_{v,n,m} \left( c_{v,n,m+1}^{(R)} + E_{v,n,m+1} - E_{v,n,m} \right)$$

$$+ \; C_{v,n,m-1} \left( c_{v,n,m-1}^{(R)} + E_{v,n,m-1} - E_{v,n,m} \right)$$

$$\left. + \; (WK)_{v,n,m} \, H_{n,m} \sum_{w \neq v} (WK)_{w,n,m} \, c_{w,n,m}^{(R)} \right] S_{v,n,m}^{-1} - \left. c_{v,n,m}^{(R)} \right\} \quad (18)$$

where $\Omega$ is the over-relaxation factor. An $\Omega$ value of 1.5 is generally recommended in this application.

Twenty passes are specified for the blending calculations—the sequence of four alternate orderings is repeated five times. The solution is estimated by

$$c_{v,n,m}^{*} = c_{v,n,m}^{(20)} \quad . \tag{19}$$

### 3.1.3   Provisions and Additional Features

#### 3.1.3.1   Exploitation of Independent Sea-Surface Temperature Information

The summation which appears in Eq. (10) couples the adjustments of those several channels of spot $n, m$ which participate in a local adjustment axis of calculated components, $K_v$. The associated component weights, $W_v$, are non-zero only to the depth of optimum two-state interpretation. If $W_6 \neq 0$ then the two-state interpretation is locally applied to the full _atmospheric_ column, and $W$ and $K$ values for channels 7 and 8 will also have been calculated.

The _optimum_ length factor, $L_{n,m}$, for amplification or reduction of the local adjustment vector, is determined by Eq. (8), which contributes the summation term appearing in Eq. (10). We consider that inclusion of the water-vapor channel, channel 8, would weaken the optimization expressed by the summation. The upper limit of the summation may be set to include up to channel 6, or up to channel 7.

The purpose of including channel 7 in the summation would be to exploit independent sea-surface-temperature (SST) estimates. We prefer to limit such exploitation to cycles 1 and 2, for help in purifying the diagnosis of information elements, but leaving the final product of cycle 3 independent of any direct SST information.

The inclusion of channel 7 in the adjustment axis is further limited to open-sea areas. This is done by multiplying the weight, $W_{7, n, m}$, by the land/sea delta functions for the spot, $n, m$, itself, and for the four ambient spots: $n-1, m$ ; $n+1, m$ ; $n, m-1$ ; $n, m+1$. If any of these five spots is land ($\delta = 0$) then this multiplication makes $W_{7, n, m} = 0$.

The same land/sea delta functions are used to multiply the continuity imposition on the window channel radiance between spots which are not both sea:

$$B_{7,n,m} \text{ is multiplied by } \delta_{n,m} \, \delta_{n+1,m} \text{, and}$$

$$C_{7,n,m} \text{ is multiplied by } \delta_{n,m} \, \delta_{n,m+1} \, .$$

### 3.1.3.2  The Variable Axis Weights

The blending system of equations represented by Eq. (10) includes some non-linearity. This can be noted from Eq. (6): The weight $W_{v,n,m}$ is the weight which is associated with the estimate $L_{n,m} \, K_{v,n,m}$. In the diagnosis of information elements, an associated variance, $\sigma^2_{v,n,m}$, is calculated for each $K_{v,n,m}$ element. When $K_{v,n,m}$ is multiplied by the factor $L_{n,m}$ then the associated variance is $L^2_{n,m} \, \sigma^2_{v,n,m}$. We have also chosen to add a lower-bounding base increment to $L^2_{n,m}$, as function of cycle number, (c):

$$W_{v,n,m} = \frac{1}{\left( L^2_{n,m} + a^{(c)}_9 \right) \sigma^2_{v,n,m}} \tag{20}$$

where $a^{(c)}_9$ is one set of the many adjustable constants contained in the job stream.

$L^2_{n,m}$ and $\sigma^2_{v,n,m}$ are also functions of the cycle number because they are recalculated in each cycle. $L_{n,m}$ is given by Eq. (6). The best approximations of $\sigma^*_{v,n,m}$ that are available at the beginning of each cycle are used to calculate $L_{n,m}$ for that cycle. In the first cycle the first-guess adjustment values are used to approximate $L_{n,m}$. In the second and third cycles the results of the preceding cycle are used.

-46-

### 3.1.4   The Associated Resolution Weights

The associated resolution weights, $A^*_{v,n,\pi}$, are calculated only for the products of cycle three--for the final diagnosed equivalent clear-column radiance estimates, $E_{v,n,\pi} + c^*_{v,n,\pi}$. Although the weights would be of value in the diagnosis of information elements in cycles two and three, the $A^*$ calculations are too costly to include in cycles one and two.

Equation (10) represents a system of equations which may be written in matrix notation:

$$\underset{\approx}{M}\ \underset{\sim}{c}^* = \underset{\sim}{E} \ . \tag{21}$$

The elements of the matrix $\underset{\approx}{M}$ are formed only from information weights. All estimate values appear in the forcing vector, $\underset{\sim}{F}$. In FIB applications the matrix $\underset{\approx}{M}$ is symmetric and positive definite. The formal explicit solution is expressed by

$$\underset{\sim}{c}^* = \underset{\approx}{M}^{-1}\ \underset{\sim}{F} \ . \tag{22}$$

According to the FIB methodology the associated resolution weights of the resultant estimates, are given, inverted, by the diagonal elements of the inverse matrix. This is explained by Holl and Mendenhall (1971).

In the present application the dimension of the vector for the 6 atmospheric channels is

$$6 \times 21 \text{ spots} \times 9 \text{ scanlines} = 1134 \text{ elements} \ .$$

Two spots at the end of each scanline are omitted because of limited ambient information density; they are exploited in the diagnosis components. The

dimensions of the matrix, 1134x1134, make explicit inversion too costly; for that reason Blending-by-Weighted-Spreading and Successive-Over-Relaxation methods have been developed for computation of approximate solutions for the $c^*$ values.

In the present application the continuity coupling between scanlines is imposed by the weights, $C_{v,n,\pi}$ . In cycle three these weights are set rather low because the scanlines are far apart, in terms of the object scale of resolution.

The cost of the calculation of $A^*$ is made acceptable by ignoring the coupling between scanlines and evaluating the resolutions for each scanline, as a consequence of only the information elements of that scanline. A 126x126 matrix is inverted for each scanline. Each such matrix is tridiagonal in terms of submatrices: Full 6x6 matrices in the diagonal and diagonal 6x6 matrices off the diagonal. These elements are formed for each scanline, and a subroutine called SINV[1] is used to invert the matrix. Nine such matrices are inverted for the determination of the $A^*_{v,n,\pi}$ array. The details are given in the Program Documentation.

## 3.2    Formulations for the Preprocessing Components

The preprocessing components are rather straightforward and they are adequately described in Section 1.4.1. The algorithms can be followed in detail with the Program Documentation. Each scanline is preprocessed separately.

We have already stated that, for simplicity and convenience, the standard values and transforms are calculated for each scanline, only for zenith angles of 0 degrees and 30 degrees. The interpolation/extrapolation for the zenith angle of spot n, $Z_n$ , is linear in a new parameter defined by

---

[1]Subroutines SINV and MFSD are included in IBM's Scientific Subroutine Package, Version III (August 1970).

$$\text{ZCOS}_n = \frac{1 - \cos Z_n}{1 - \cos 30^\circ} \quad . \tag{23}$$

For example, an arbitrary quantity $Q$, is interpolated for spot $n$ according to the formula

$$Q_n = Q_0 + \left(Q_{30} - Q_0\right) \text{ZCOS}_n \tag{24}$$

where $Q_0$ and $Q_{30}$ are the values for zenith angles of zero and thirty degrees, respectively.

The interpolations of independent temperature information, from analyzed fields in grid-point arrays, make use of special FNWC subroutines:

(i)  INTRP is used for interpolation in upper-air, isobaric, temperature fields. It is based on zero and first-order continuity everywhere.

(ii) INTRPS is used for interpolation in sea-surface temperature fields--fields whose continuity is interrupted by islands and land features. INTRPS bases interpolations on the continuity of water-mass regions, as specified by the field of Spatial-Covariance Dissociation (SCD) for the pertinent SST-analysis grid.

These subroutines are developments of MII.

## 3.3 Formulations for the Diagnosis of Information Elements

### 3.3.1 Absolute Estimates

The information elements and notations are introduced in Sections 1.4.2.2 and 3.1. The diagnosis of information elements involves many details to cope with the limited significance given measured radiances, and with the sparsity of spots. Many features, provisions and adjustable constants are included for the progressive purification of information elements from cycle to cycle. Many of these details are tedious to itemize but then they are easily followed in the Program Documentation. This is particularly true of details for assessing that a preprocessed radiance, $E_{v,n,\pi}$, may be cloud free, and for calculating a suitable associated weight, $A^e_{v,n,\pi}$. The assembly of these estimates, together with weighted first-guess estimates of atmospheric and window channels, is expressed by Eqs. (3) and (4).

### 3.3.2 Adjustment Axes

The diagnosis of local adjustment axes, and associated weights, is based on establishing the local relevance of the two-state cloud-structure interpretation model.

The diagnosis for arbitrary spot $n,\pi$ proceeds as follows. Components of local contrast vectors are calculated:

$$D_{j,v} = S_j a_j \left( E_{j,v} - E_{0,v} \right) \tag{25}$$

where subscript $j$ refers to ambient spots: $1 = n-1,\pi$ ; $2 = n+1,\pi$ ; $3 = n-2,\pi$ ; $4 = n+2,\pi$ ; $5 = n,\pi+1$ , with $n-1,\pi-1$ serving as alternate if spot $n,\pi$ is on the last scanline of a block: $6 = n,\pi-1$ , with $n-1,\pi-1$ serving as alternate

if spot $n,m$ is on the first scanline of a block. And $j = 0$ refers to the $n,m$ spot itself. $S_j$ is a sign-normalization factor for vector $\underset{\sim}{D}_j$:

$$S_j \equiv \frac{\sum_{v=1}^{6} \left( E_{j,v} - E_{0,v} \right)}{\left| \sum_{v=1}^{6} \left( E_{j,v} - E_{0,v} \right) \right|} \quad . \tag{26}$$

Each component of vector $\underset{\sim}{D}_j$, as defined by Eq. (25), also includes a weight factor, $a_j$, assigned on the basis of the proximity of the $j$ spot to the $0$ (i.e., $n,m$) spot--the closer the spot the larger is this weight.

A seventh vector, $\underset{\sim}{D}_7^{(c)}$, is similarly defined, based on differencing with the best available estimates of the local objectives:

$$D_{7,v}^{(c)} = S_7^{(c)} a_7^{(c)} \left( E_{0,v}^{(c)} - E_{0,v} \right) \tag{27}$$

where $E_{0,v}^{(1)}$ for cycle one is based on the available first-guess calculations, and $E_{0,v}^{(2)}$ for cycle two is the resultant of cycle one, and $E_{0,v}^{(3)}$ for cycle three is the resultant of cycle two. The weight factor, $a_j^{(c)}$, is specified to be rather small in cycle one, because of lack of confidence in calculated first-guess radiances, and considerably larger in cycles two and three.

The local optimum depth of validity of a two-state model interpretation is based on the coherance of these seven vectors for component-subset ranges 1-3, 1-4, 1-5, and 1-6. Whichever of these subsets is judged to have best coherance determines the subset of channels which will be related by a local adjustment axis. The following calculations are designed for this determination.

The array of partial-vector lengths squared:

$$L_{j,w}^2 = \sum_{v=1}^{w} D_{j,w}^2 \tag{28}$$

for $j = 1-7$, and the summation upper limits $w = 3, 4, 5$ and $6$.

A _mean_ of the direction cosines, made by _each_ vector $j$, with respect to each of the set of seven vectors, in each subset $w$, is defined as follows:

$$\cos_{j,w}^2 \equiv \frac{\displaystyle\sum_{i=1}^{7} \left\{ \sum_{v=1}^{w} D_{i,v} D_{j,v} \right\}^2}{\displaystyle\sum_{i=1}^{7} L_{i,w}^2 L_{j,w}^2} \tag{29}$$

where $i$ has been introduced as a dummy subscript for $j$. This mean is formed by weighting each contributing cosine squared by the lengths squared of the pair of vectors which define the cosine.

The _mean_ of the set of seven means calculated by Eq. (29), in each subset $w$, is defined as follows:

$$\cos_{w}^2 \equiv \frac{\displaystyle\sum_{j=1}^{6} \left\{ \left\{ \sum_{i=1}^{7} L_{i,w}^2 L_{j,w}^2 \right\} \cos_{j,w}^2 \right\}}{\displaystyle\sum_{j=1}^{6} \left\{ \sum_{i=1}^{7} L_{i,w}^2 L_{j,w}^2 \right\}} . \tag{30}$$

The weighting imposed is apparent. That $w$, of the subset 3, 4, 5 and 6, for which $\cos_{w}^2$ is a maximum is selected by the program as indication of

the optimum local depth of compliance with a two-state interpretation model. Denote this best $w$ by $u$, and its coherence measure by $\cos^2_u$.

A quality minimum must be met in each cycle before deciding to calculate local axis components and weights. It is required that $\cos^2_u$ exceed a uniform lower bound which is specified for each cycle. These lower bounds are presently set at 0.25, 0.5, and 0.75, for cycles one, two, and three, respectively.

If the quality minimum is met, and if $u < 6$, then axis components, $K_v$, and associated weights, $W_v$, are calculated only for $v = 1, 2 \ldots u$. All $W_v$ for $v > u$ are set to zero. If $u = 6$ then supplemental components and associated weights are also calculated for channels 7 and 8. In the blending, channel 8 is not permitted any influence on the other channels. The influence of channel 7 is also limited. These controls are discussed in Section 3.1.3.1.

Details for the calculation of axis components and weights are given in the Program Documentation.

3.3.3   Horizontal Continuity

All the information that is available with regard to spot-to-spot differences, in clear-column radiance components, is inherent in the array of calculated first-guess radiances for the six atmospheric channels, and for the window channel. After preprocessing of the measured radiances this information is condensed into zero spot-to-spot differences everywhere—estimates which are weighted locally by $B_{v,n,-}$ and $C_{v,n,-}$.

Not noting any basis for keeping these weights dependent on spot number, beyond dependence on the land/sea delta function for the window channel, and desiring to cut down on storing arrays, we made the following simplifications.

For channels 1 through 6:

$$B_{v,n,m} = B_v^{(c)}$$

$$C_{v,n,m} = 0.1 \, B_v^{(c)} \quad . \tag{31}$$

For channel 7 the delta functions are incorporated:

$$B_{7,n,m} = \delta_{n,m} \, \delta_{n+1,m} \, B_7^{(c)}$$

$$C_{7,n,m} = \delta_{n,m} \, \delta_{n,m+1} \, 0.1 \, B_7^{(c)} \quad . \tag{32}$$

That C is specified to be smaller than B reflects the larger separation between scanlines compared to the separation of spots adjoining in a scanline.

The three-cycle design of the information-diagnosis-and-blending components is primarily motivated for purposes of screening and purifying the diagnosed inherent elements of information. This purpose is aided by setting the $B_v^{(c)}$ values large in cycle one, with appropriate channel-to-channel differences, in order to focus resolution on a corresponding large scale for each radiance-anomaly field. The resulting blended resolutions are higher--legitimately so to some extent--in correspondence to this object scale of resolution.

The $B_v^{(c)}$ weights are set to, what we may call, medium values for cycle two, and small values to effect the objective scale of resolution in cycle three. This design is considered advantageous for a systematic purification of information elements.

## 3.4    Formulations for the Thermal-Structure Blending

### 3.4.1    The Functional and the System of Blending Equations

The Thermal-Structure Blending (TSB) capability is designed for single-column applications, and may be applied to many columns in sequence. The thermal-structure profile is represented by the potential temperature, $\theta_i$, for each of the nineteen pressure levels, $p_i$, listed in Section 1.4.1.2. By choice the surface value is not included.

The functional is defined by

$$F \equiv \sum_i A_i \left( \theta_i^* - \theta_i \right)^2 + \sum_v R_v \left( \sum_j k_{v,j} \theta_j^* - r_v \right)^2 \quad . \tag{33}$$

Notation:

$A_i$    is the weight associated with the direct estimate $\theta_i$.

$r_v$    is an estimate of a linear combination of potential-temperature elements:

$$\sum_j k_{v,j} \theta_j^*$$

where j is used as a dummy subscript for i.

$R_v$    is the weight associated with the combination estimate $r_v$.

Several combination estimates are included in the functional.

Setting $\partial F/\partial \theta_i^* = 0$ yields the arbitrary i-th component of the simultaneous system of blending equations:

$$A_i \left( \theta_i^* - \theta_i \right) + \sum_v R_v k_{v,i} \left( \sum_j k_{v,j} \theta_i^* - r_v \right) = 0 \quad . \quad (34)$$

The blending system of equations may be expressed in matrix notation:

$$\underset{\approx}{K} \; \underset{\sim}{\theta}^* = \underset{\sim}{F} \tag{35}$$

where $\underset{\sim}{\theta}^* \equiv \left( \theta_1^*, \; \theta_2^*, \; \theta_3^*, \; \ldots \; \theta_{19}^* \right)^T$. The matrix $\underset{\approx}{K}$ has i-labeled rows and j-labeled columns. The diagnoal elements, $i = j$, are

$$A_i + \sum_v R_v k_{v,i}^2 \quad ,$$

and the off-diagonal elements, $i \neq j$, are

$$\sum_v R_v k_{v,i} k_{v,j} \quad .$$

The matrix is symmetric and positive definite. The elements of the forcing vector $\underset{\sim}{F}$ are given by

$$A_i \theta_i + \sum_v R_v k_{v,i} r_v \quad .$$

### 3.4.2 The Blending Solution

The blending system of equations can be solved explicitly by direct matrix inversion, using subroutine SINV.

$$\underline{\theta}^* = \underset{\approx}{K}^{-1}\ \underline{F}\ .\tag{36}$$

The associated resolution weights, $A_i^*$, appear inverted in the diagonal elements of $\underset{\approx}{K}^{-1}$ .

This explicit solution, however, is not constrained to be a statically-stable thermal profile. It may or may not be stable. The stability check is applied sequentially in $i$ (i.e., downward in the atmospheric column) requiring that

$$\theta_i^* \leqq \theta_{i-1}\ .$$

Any level found to be in violation is immediately adjusted to the limit before proceding to the next level.

If any violations have been found then the adjusted column solution is optimized by constrained SOR blending. The ordering is again sequential in $i$. The SOR algorithm for Eq. (34) is

$$\theta_i^{(R+1)} = \theta_i^{(R)}$$

$$+ \omega \left\{ \frac{A_i\,\theta_i - \sum_v R_v k_{v,i} \left[ \sum_{j=i} k_{v,j}\,\theta_j^{(R)} - c_v \right]}{A_i + \sum_v R_v k_{v,i}^2} - \theta_i^{(R)} \right\}$$

$$\leqq \theta_{i-1}^{(R+1)} \quad \text{as imposed limit.}\tag{37}$$

An arbitrary five passes are specified using $\omega = 1.5$.

### 3.4.3 Input Transformations

It is a simple matter to convert a direct temperature estimate, $T_i$, of associated weight, $(A_i)_T$, into a direct potential-temperature estimate, $\theta_i$, of associated weight, $(A_i)_\theta$:

$$\theta_i = P_i T_i \tag{38}$$

$$(A_i)_\theta = P_i^{-2} (A_i)_T \tag{39}$$

where

$$P_i \equiv \left( p_o / p_i \right)^\kappa \tag{40}$$

and $p_o$ = 1000 mb. Units for $T$ and $\theta$ are degrees Kelvin.

The combination estimates and associated weights are derived from

(i)  the diagnosed and restored clear-column radiances, $E_v$, (not including restoration of the surface anomaly contributions) for the six atmospheric channels, and their resultant associated weights, $A_v^*$, and

(ii)  channel radiance relationships to the thermal-structure profile.

To demonstrate the capability we have used the relationships calculated from available transmission functions for zero zenith angle, based on linearization about a local standard atmosphere (see Section 1.4.1.2):

$$E_v - E_{v,s} = \sum_i^{19} C_{v,i} \left( T_i - T_{i,s} \right) . \tag{41}$$

The subscript S refers to the local standard values. Note that the diagnosed radiances, $E_v$, include the local standard surface contributions, but not the surface-anomaly contributions. The standard radiances, $E_{v,s}$, include atmosphere and surface contributions.

Equation (41) is transformed into

$$r_v = \sum_i k_{v,i}\, \theta_i \quad .$$

(42)

It follows that

$$r_v = E_v - \left( E_{v,s} - \sum_i C_{v,i}\, T_{i,s} \right)$$

(43)

$$k_{v,i} = p_i^{-1}\, C_{v,i}$$

(44)

and

$$R_v = \frac{1}{\left( A_v^* \right)^{-1} + \sigma_v^2}$$

(45)

where the added variance, $\sigma_v^2$, is attributed to the thermal-profile relationship for channel v.

The resultants of the thermal-structure blending are transformed back into temperature, $T_i^*$, and associated resolution weights, $A_i^*$. The radiances implied by this profile are also calculated for checking calibration consistencies between channels.

-53-

# 4.  SUMMARY AND CONCLUSIONS

## 4.1  Benefits of the New Capabilities

Many improvements, both major and minor, have been formulated and implemented into the design of the CLRBLOK job stream, to extend applicability and to increase the information yield.

The powers of the combined Blending by Weighted Spreading (BWS) and Successive Over-Relaxation (SOR) capabilities for solving the blending system of equations make the entire complex diagnosis feasible and practical.  Meaningful solutions are assured, within the context of practical considerations related to computer-system capabilities.

The preprocessing components of CLRBLOK extend applicability into regions where the surface temperature may be quite pronounced--into regions which may include islands and land areas of low elevation.  These components all enhance the applicability of the diagnostic model and concepts.  The values and transforms which are applied in the preprocessing components are based on available transmission functions, and on specification of a local standard temperature profile for each scanline.

The diagnosed clear-column radiance components are available in nadir-normalized form--i.e., all values are made equivalent to zero zenith-angle measurements.  This feature improves the utility of the data in many contexts.

The two-state diagnostic model--which allows a mix of only one cloud-top and one clear component--is imposed only to the optimum depth of model compliance.  This new CLRBLOK feature increases the yield for the lower-numbered channels, and removes a source of bias in the yield for the deeper-viewing channels.

The CLRBLOK capability exploits calculated first-guess radiances both directly, as absolute estimates, and indirectly, as spot-to-spot differences in both horizontal dimensions. The sea-surface-temperature (SST) information in open seas is considered to be particularly valuable. These contributions can all be separately controlled in each of the three cycles. In cycle three the independent information is exploited only indirectly, thus freeing the resultant clear-column radiances from absolute biases which can be introduced by the independent temperature information and by the available transmission functions.

Whenever the necessary conditions of horizontal uniformity occur, the yield of diagnosed information extends to channels 7 and 8. This yield for the window channel represents a valuable source of independent SST information which can be exploited directly, if adequately calibrated, and indirectly in SST analysis.

The Thermal-Structure Blending (TSB) capability assimilates the relevant information in clear-column radiances according to the associated reliability weights, and contributing variances. [The contributing variances are associated with the calibration of channel atmospheric source functions.] Comparable reliabilities are not required of all channels of a spot. Upper channel information is assimilated where there may be limited yield for the deeper viewing channels. The TSB capability also exploits the information that the atmosphere is statically stable in the object scale of resolution.

The TSB capability provides 19 standard pressure levels, including considerable resolution in the upper atmosphere, for the exploitation of calibrated clear-column radiance estimates.

## 4.2 Limitations

The powers and features of the CLRBLOK job stream alone do not guarantee any information yield from the system. The CLRBLOK capability only diagnoses and organizes relevant information that is inherent in the block of radiance measurements. The amount of inherent information realized in the yield is dependent on the design of the remote sensors and of the scanning geometry, on the reliability of channel calibrations in terms of atmospheric source functions, on the local cloud-structure characteristics, and on the tuned analysis powers of the processing job stream.

The CLRBLOK capability uses available transmission functions to calculate standard radiances, and linearized transformations, for a local standard atmosphere specified for each scanline, but includes no components for refining the transmission functions. The accuracy is of secondary significance in the diagnosis of clear-column radiance components, except for the accuracy required in the proportion of the surface contribution in each channel relative to the window channel. As presently designed, the exploitation of clear-column radiances for enhanced atmospheric thermal-structure resolution by use of the TSB capability is directly dependent on the accuracy of the transmission functions.

The value of the system can also be limited by capabilities of the upper-air analysis system.

## 4.3 Recommendations

The CLRBLOK job stream is suitable for implementation in an operational context. The Thermal-Structure Blending (TSB) capability is a tentative design enabling exploitation of calibrated clear-column radiances for enhanced atmospheric thermal-structure resolution. The relationships between clear-column radiances and atmospheric thermal-structure variabilities should not

rely on theoretical calculations alone, but should be statistically refined and evaluated. The TSB capability should be disengaged until an adequate sample of clear-column radiances has been produced by CLRBLOK diagnosis, and corresponding independent thermal-profile data is collected and analyzed for development of a transform-generating subroutine.

The independent temperature profile data need not be complete in the sense of _uniform_ reliability of the complete atmospheric thermal profile. Each profile should be specified by a temperature estimate and corresponding reliability weight for each level of a set of standard pressure levels. Such weighted profiles are useful even if resolution is completely lacking at high altitudes. Similarly, high altitude soundings, without concurrent resolution at low altitudes, can be exploited for statistical calibration of channel radiances.

The CLRBLOK job stream must be tuned under quasi-operational conditions. Most minor adjustments would hardly be noticeable in the end results but can be studied for their specific effects within component operations. The print options should be exploited for this work. Minor adjustments of several tunable constants can add up to significant increases in yield.

We have expressed a position in regard to ideal model concepts and corresponding system specifications for the remote sensing of the atmospheric thermal structure. We hope these views will be considered, and that they will be found helpful, in future system developments. The CLRBLOK diagnostic model can also be revised to exploit Factor Analysis, and a three-state adjustment plane.

The CLRBLOK diagnostic model does not include the capability for exploiting coincident microwave channels. The model can be revised to include such exploitation. Just one optimum microwave channel should make a valuable contribution to the information yield of clear-column radiances for all channels.

Several further installments or phases of development can be recommended. These have to do with refinements and variations in the context of--or in relationship with--a comprehensive atmospheric analysis and prediction system.

An advanced system design would supersede the TSB capability with analysis of the horizontal distribution of clear-column radiances--one field per channel--in conjunction with a more comprehensive atmospheric mass-structure blending system. The clear-column radiances, diagnosed by CLRBLOK, could be accrued in space and time. An analysis system can be developed which combines diagnosed clear-column radiances with radiance estimates calculated from radiosondes, with calibration determined entirely from the radiosonde-calculated radiances. The analyzed radiance distributions would then be in complete calibration agreement with the transforms applied to the radiosondes for calculating radiances.

Part 1 of CLRBLOK contains a provision for linear transformation of the measured radiances in order to effect an implicit rearrangement of the channel source functions of the clear-column components. The provision follows implicit nadir normalization. The objective would be source functions of more distinct--more sharply defined--depth ranges, in monotonic order of depth. Such optimized transforms can be developed and may be beneficial in improving the cloud interpretation model, and diagnosis by CLRBLOK.

## 5.    REFERENCES

Holl, Manfred M. and Bruce R. Mendenhall, 1971; "Fields by Information
    Blending, Sea-Level Pressure Version", Final Report (Contract
    N66314-70-C-5226, Fleet Numerical Weather Central), Meteorology
    International Incorporated, Monterey, California, 66 pp.

Holl, Manfred M., 1972; "The Development of Techniques for Operational
    Exploitation of Satellite Infrared Channel Radiances in the Resolution
    of Atmospheric Thermal-Structure Variabilities, Task One:  Perspective",
    Technical Report of Task One (Contract N62306-72-C-0125,
    Environmental Prediction Research Facility), Meteorology International
    Incorporated, Monterey, California, 61 pp.

Holl, Manfred M., 1973a; "The Development of Techniques for Operational
    Exploitation of Satellite Infrared Channel Radiances in the Resolution
    of Atmospheric Thermal-Structure Variabilities, Task Two:  New
    Formulations", Technical Report of Task Two (Contract N62306-72-C-
    0125, Environmental Prediction Research Facility), Meteorology
    International Incorporated, Monterey, California, 30 pp.

Holl, Manfred M., 1973b; "The Development of Techniques for Operational
    Exploitation of Satellite Observed Sounding Data for Resolution of
    Atmospheric Thermal-Structure Variabilities, Task Three and Final
    Report", Technical Report of Task Three and Final Project Report
    (Contract N62306-72-C-0125, Environmental Prediction Research
    Facility), Meteorology International Incorporated, Monterey,
    California, 59 pp.

Holl, Manfred M., 1975a; "The Development of Techniques for Operational Exploitation of Satellite-Observed Sounding Data for Resolution of Atmospheric Thermal-Structure Variabilities, Phase Two: Techniques for Processing VTPR Side-Scan Radiances including Diagnosis for the Clear-Column Radiance Components", Technical Summary Report (Contract N66314-74-C-1281, Environmental Prediction Research Facility), Meteorology International Incorporated, Monterey, California, 93 pp.

Holl, Manfred M., 1975b; "Tests and Evaluations of CLRX, The Diagnosis of Clear-Column Radiances", Final Report (Contract N00228-75-C-2362, Naval Environmental Prediction Research Facility), Meteorology International Incorporated, Monterey, California, 32 pp.

Holl, Manfred M. et al., 1976a; "Full-Scan Clear Radiances from Measured Cloud-Contaminated VTPR Radiances--A Description of Program CLRXN", Final Report (Contract 6-35187, National Environmental Satellite Service, NOAA), Meteorology International Incorporated, Monterey, California, 22 pp. plus Appendix A.

Holl, Manfred M., 1976b; "The Upper-Air Analysis Capability, FIB/UA Introducing Weighted Spreading", Final Report (Contract N00228-75-C-2374, Fleet Numerical Weather Central), Meteorology International Incorporated, Monterey, California, 32 pp. plus Appendix A.

Lorenz, E. N., 1956; "Empirical orthogonal functions and statistical weather prediction", Scientific Report No. 1, Statistical Forecasting Project, Massachusetts Institute of Technology, Cambridge, Massachusetts, 49 pp.

McMillan, L. M., et al., 1973; "Satellite Infrared Soundings from NOAA Spacecraft", <u>NOAA Tech. Report. NESS 65</u>, U. S. Department of Commerce, Washington, D. C., 112 pp.